Evaluation of greenhouse gas emissions avoided in 2024 attributable to the portfolio of wind energy, photovoltaic and biogas installations financed by Landwirtschaftliche Rentenbank

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Contents

List of Tables

List of Figures

Abbreviations and explanations

CO_2	Carbon dioxide
CO_{2eq}	see CO_2-equivalent
CO_2-equivalent	Unit used for measuring the global warming potential (i.e. the potential contribution to the warming of near-surface layers of the atmosphere) of a greenhouse gas in relation to the effect of CO_2. It states the quantity of CO_2 that would have the same greenhouse effect as the gas in question over a period of 100 years. For instance, one kg of methane (CH_4) has the same effect as 28 kg of CO_2.
GHG	Greenhouse gas
GWh	Gigawatt hour(s); 1 GWh = 1 million kWh
kW	Kilowatt(s)
kW_p	Kilowatts peak: peak power of PV facilities
kWh	Kilowatt hour(s)
kt	Kilo tonne (1,000 tonnes)
MW	Megawatt(s); 1 MW = 1,000 kW
PV	Photovoltaic energy
RE	Renewable energy
RED II	Renewable Energy Directive II of the European Commission
RES	Renewable energy sources
t	(metric) Tonne

1 Introduction

The main focus of the promotional activities of Landwirtschaftliche Rentenbank (hereinafter referred to as “Rentenbank”) lies on loans for agriculture-related projects of all kinds, as well as for providing finance in rural areas. Within its loan programmes, Rentenbank supports investment in installations for using renewable energy, notably in bioenergy, wind energy and photovoltaic energy (PV). On behalf of Rentenbank ZSW developed an approach to estimate the amount of greenhouse gas (GHG) emissions avoided by photovoltaic and wind energy installations supported by the low-interest loans (see Bickel 2020). Starting with the reporting year 2022, the assessment was extended to biogas installations co-financed by the Rentenbank.

The present report describes the GHG emission savings attributable to the operation of the installations in 2024, based on the portfolio as of 31st December 2024. Figure 1 shows the installed power that can be attributed to the residual debt of loans by year of investment. An overview of the calculation approach is given in the annex.

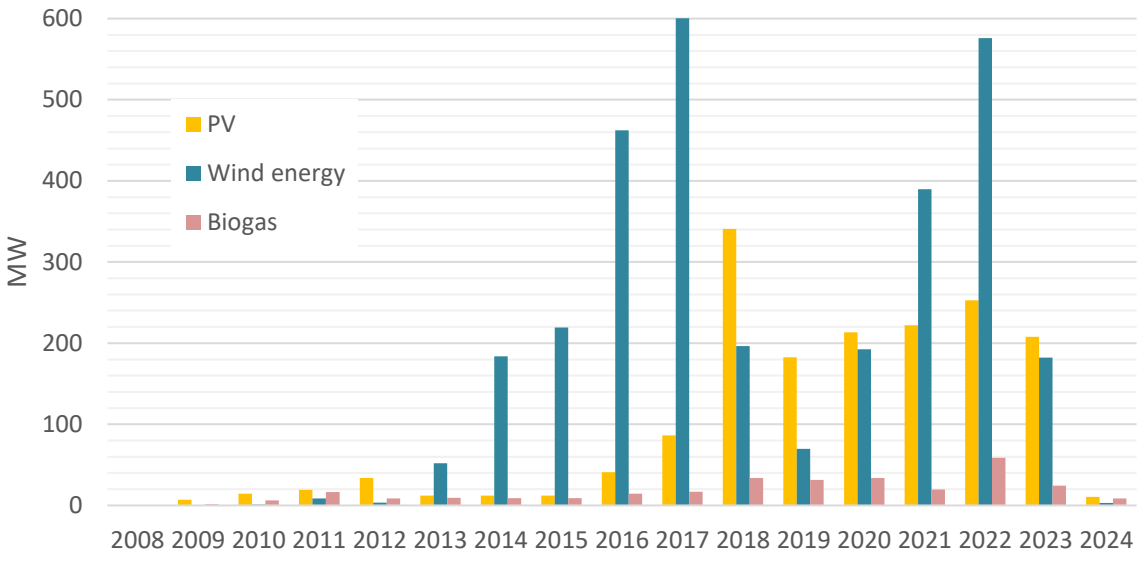

Figure 1: Installed power attributable to the residual debt of loans by year of investment (as of 31st December 2024).

2 Emission savings

In 2024, meteorological conditions in Germany deteriorated compared to the previous year for both photovoltaic and wind energy. Global solar radiation fell for the second year in a row after the exceptional year 2022. In 2024, average wind speeds returned to normal conditions after 2023 being the windiest year in over 20 years. In addition, the installed capacity of PV

and wind energy installations supported by the Rentenbank declined year-on-year. As a consequence of both developments, GHG emission savings attributable to the Rentenbank portfolio decreased for both, PV and wind energy installations. PV recorded a decline of 4 percent year-on-year. In total, 1,079,000 tonnes of CO_2-equivalent (CO_{2eq}) were avoided, as illustrated in Figure 2. For the Rentenbank wind energy installations portfolio GHG emission savings decreased by 13 percent year-on-year to 5,210,000 tonnes of CO_{2eq} (see Figure 3).

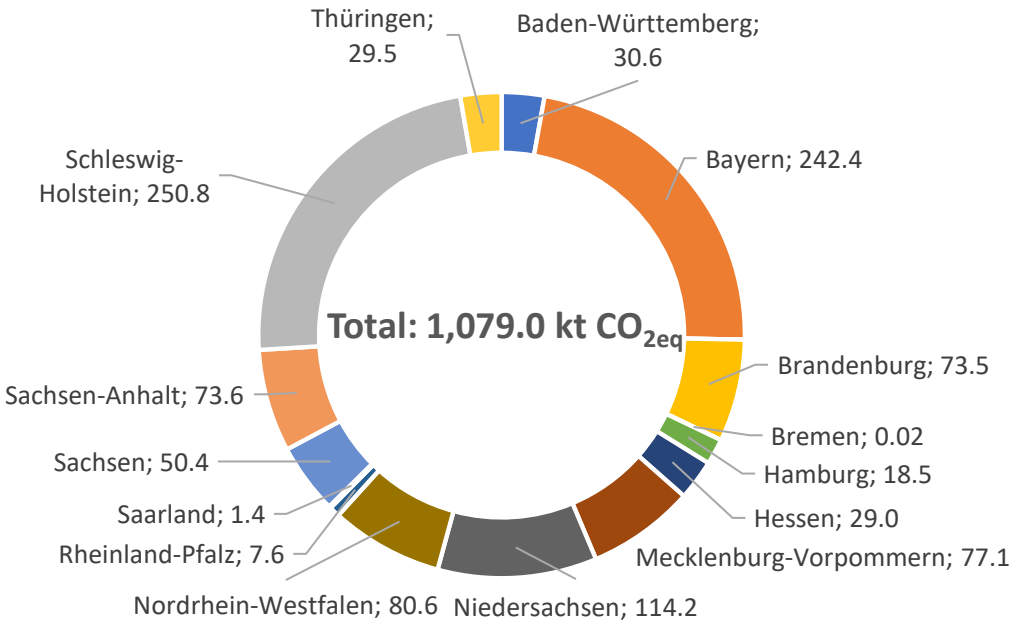

Figure 2: Greenhouse gas emission savings 2024 attributable to photovoltaic installations supported by Rentenbank loans (kt = 1,000 tonnes).

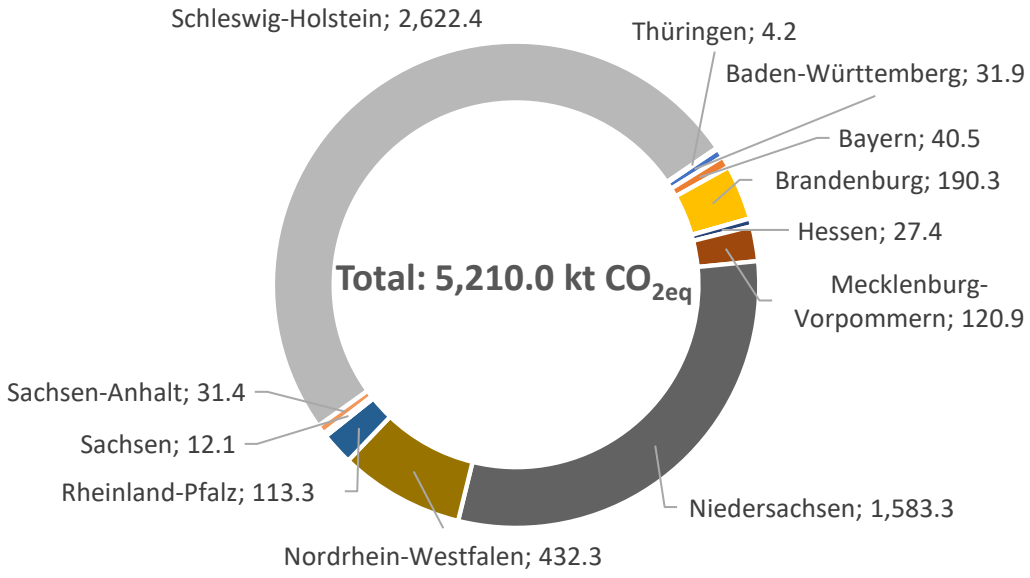

Figure 3: Greenhouse gas emission savings 2024 attributable to wind energy installations supported by Rentenbank loans (kt = 1,000 tonnes).

Electricity generation in biogas cogeneration plants is independent of meteorological conditions, which is one advantage of this technology over PV and wind energy. Figure 4 illustrates the GHG emission savings attributable to the Rentenbank portfolio of biogas installations, amounting to 711,900 tonnes of CO_{2eq}. This corresponds to a decrease of 10 percent compared to the year 2023. The decline in installed capacity of the portfolio supported was partly compensated by an increase in the emission reduction factor for methodological reasons (see Annex for more information).

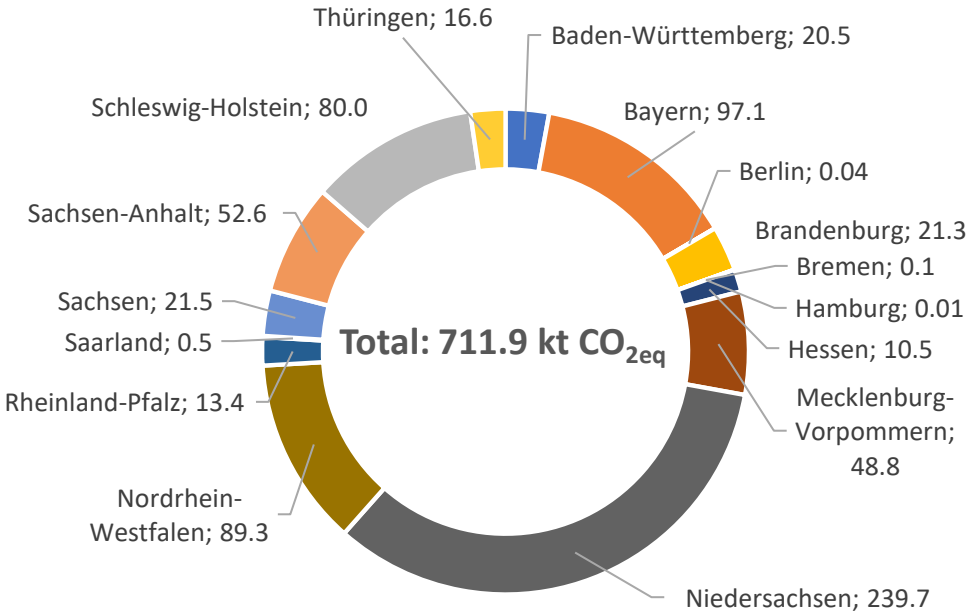

Figure 4: Greenhouse gas emission savings 2024 attributable to biogas installations supported by Rentenbank loans (kt = 1,000 tonnes).

Table 1, Table 2 and Table 3 present the results by federal state. It has to be noted that the values are aggregated across all years of investment. The average specific investment costs reflect the underlying time structure of investments in the portfolio. Large PV installations saw a substantial decline in specific investment cost from approx.. 4,600 €/kW_p in 2008 to about 800 €/kW_p in 2020, followed by a cost increase to ca. 1,000 €/kW_p in 2023 and a further drop to around 850 €/kW_p in 2024. As a consequence, considerable variation can be observed between federal states according to different financing volumes over time. High values result from early investments with higher specific costs. For wind energy installations the variation is comparably small as there was relatively little variation in specific costs between investment years (see Table 2). For biogas plants, the differences in average specific investment costs are mainly due to a high variability of specific costs by plant concepts and plant size. Specific costs tend to decrease with increasing plant size (see annex for more information).

Table 1: Loans for photovoltaic installations as of 31st Dec. 2024 and attributable effects in the year 2024, by German federal state.

	Loans		Average specific inv. cost	Attributable to loans			
	Count	Residual debt		Installed power	Electricity production	GHG emissions avoided	
		Million €	€/kW$_p$	MW$_p$	GWh	t CO_2	t CO_{2eq}
Total	**10,681**	**-1,573.1**	940	**1,668.4**	**1,564.8**	**1,005,300**	**1,079,000**
Baden-Württemberg	327	-43.4	930	46.4	44.4	28,500	30,600
Bayern	2,393	-329.1	920	357.8	351.5	225,800	242,400
Brandenburg	142	-87.6	920	95.2	106.6	68,500	73,500
Bremen	4	-0.1	2,600	0.04	0.03	21	22
Hamburg	37	-35.7	940	38.1	26.9	17,300	18,500
Hessen	197	-44.2	970	45.7	42.1	27,000	29,000
Mecklenburg-Vorpommern	276	-102.0	870	117.9	111.7	71,800	77,100
Niedersachsen	2,986	-191.7	990	193.6	165.6	106,400	114,200
Nordrhein-Westfalen	1,900	-134.3	970	138.3	116.9	75,100	80,600
Rheinland-Pfalz	227	-13.0	1,070	12.1	11.0	7,000	7,600
Saarland	6	-2.2	950	2.3	2.1	1,320	1,420
Sachsen	179	-63.7	910	69.7	73.0	46,900	50,400
Sachsen-Anhalt	264	-85.9	890	97.0	106.7	68,600	73,600
Schleswig-Holstein	1,587	-400.7	980	410.6	363.7	233,600	250,800
Thüringen	156	-39.4	910	43.5	42.7	27,400	29,500

Totals may differ due to rounding.

Table 2: Loans for wind energy installations as of 31st Dec. 2024 and attributable effects in the year 2024, by German federal state.

	Loans		Average specific inv. cost	Attributable to loans			
	Count	Residual debt		Installed power	Electricity production	GHG emissions avoided	
		Million €	€/kW	MW	GWh	t CO_2	t CO_{2eq}
Total	2,741	-4,589.7	1,460	3,145.4	6,872.9	4,868,400	5,210,000
Baden-Württemberg	14	-34.8	1,530	22.7	42.0	29,800	31,900
Bayern	84	-40.7	1,470	27.7	53.4	37,800	40,500
Brandenburg	33	-188.7	1,440	130.9	251.0	177,800	190,300
Hessen	15	-24.4	1,420	17.1	36.2	25,600	27,400
Mecklenburg-Vorpommern	63	-112.0	1,430	78.1	159.5	113,000	120,900
Niedersachsen	899	-1,419.1	1,430	990.7	2,088.7	1,479,500	1,583,300
Nordrhein-Westfalen	616	-404.5	1,430	282.0	570.3	404,000	432,300
Rheinland-Pfalz	33	-110.8	1,380	80.0	149.5	105,900	113,300
Sachsen	10	-11.9	1,370	8.7	15.9	11,300	12,100
Sachsen-Anhalt	25	-32.3	1,430	22.6	41.5	29,400	31,400
Schleswig-Holstein	944	-2,206.4	1,490	1,482.0	3,459.5	2,450,500	2,622,400
Thüringen	5	-4.2	1,500	2.8	5.5	3,900	4,200

Totals may differ due to rounding.

Table 3: Loans for biogas plants as of 31st Dec. 2024 and attributable effects in the year 2024, by German federal state.

	Loans		Average specific inv. cost	Attributable to loans			
	Count	Residual debt		Installed power	Electricity production	GHG emissions avoided	
		Million €	€/kW$_p$	MW$_p$	GWh	t CO$_2$	t CO$_{2eq}$
Total	5,624	-1,229.2	4,070	301.8	1,335.3	925,800	711,900
Baden-Württemberg	141	-37.2	4,240	8.8	38.5	26,700	20,500
Bayern	1,244	-186.3	4,320	43.1	182.1	126,200	97,100
Berlin	1	-0.1	7,210	0.01	0.07	46	35
Brandenburg	91	-31.0	3,810	8.1	40.0	27,700	21,300
Bremen	1	-0.1	4,340	0.0	0.1	100	73
Hamburg	1	0.0	2,880	0.01	0.03	19	15
Hessen	112	-22.2	4,440	5.0	19.8	13,700	10,500
Mecklenburg-Vorpommern	180	-65.8	3,850	17.1	91.5	63,400	48,800
Niedersachsen	1,991	-420.7	4,070	103.3	449.6	311,700	239,700
Nordrhein-Westfalen	532	-159.0	3,960	40.1	167.4	116,100	89,300
Rheinland-Pfalz	66	-24.7	4,330	5.7	25.1	17,400	13,400
Saarland	8	-1.3	5,680	0.2	1.0	700	500
Sachsen	120	-33.8	4,140	8.2	40.2	27,900	21,500
Sachsen-Anhalt	235	-85.5	3,750	22.8	98.7	68,400	52,600
Schleswig-Holstein	781	-133.0	4,140	32.1	150.0	104,000	80,000
Thüringen	120	-28.5	3,980	7.2	31.1	21,600	16,600

Totals may differ due to rounding.

Table 4 shows the comparison of the GHG emissions avoided per kWh of electricity produced with the corresponding values calculated for the total 2024 electricity production from PV, onshore wind installations and biogas plants in Germany reported in BMWK (2025). The specific GHG-avoidance factors show very good agreement for all three plant types.

Table 4: GHG emissions avoided per kWh.

g CO$_{2eq}$ / kWh	Rentenbank	BMWK (2025)	Relative Difference
Photovoltaic energy	690	690	0.003 %
Wind energy onshore	758	758	0.005 %
Biogas cogeneration	533	535	0.3 %

A further comparison based on the amount of CO_{2eq} avoided per Euro invested (see Table 5) is made to check the plausibility for the parts of the calculation with the highest uncertainty. The values of the Rentenbank portfolio are compared with the latest published figures (year 2020) for the RE loan programmes assessed in Bickel and Kelm (2021). The Rentenbank portfolio 2024 avoided less GHG emissions per invested Euro than the loan programmes 2020 for PV and biogas, for wind energy the avoidance was higher. Besides differences in meteorology between the years considered, the composition of the portfolio is an important reason for the different specific avoidance of GHG emissions: The Rentenbank PV portfolio includes installations from 2008 to 2024 with high specific investment costs for the earlier years, resulting in comparably high average specific cost of investment (see Table 1) and

thus finally to lower values regarding GHG emissions avoided per invested Euro. The corresponding value for the year 2018 (based on Bickel and Kelm 2019) with underlying similar specific cost of investment, is 21.8 percent lower than the current value of the Rentenbank PV portfolio. This is mainly due to a lower GHG avoidance factor in 2018. Thus, the emissions avoided per Euro of investment of the Rentenbank PV portfolio lie within the range of the comparative values. For wind energy installations, the Rentenbank portfolio 2024 shows a higher avoidance than the comparative values of 2020 and 2018, which is due to a combination of lower specific investment costs and a lower GHG avoidance factor in 2018. For biogas plants the comparison shows good agreement, considering the high uncertainties involved in determining average specific investment costs and estimating installed power as well as generated electricity attributable to the Rentenbank portfolio.

Table 5: GHG emissions avoided per €.

g CO_{2eq} / €	Rentenbank	Bickel and Kelm (2021, 2019)		Relative Difference	
year	2024	2020	2018	2020	2018
Photovoltaic energy	686	831	563	17.5 %	-21.8 %
Wind energy onshore	1,135	1,130	1,060	-0.5 %	-7.0 %
Biogas cogeneration	579	561	542	-3.2 %	-6.8 %

Concluding remark

The calculations presented are estimates based on limited information and to the best of our knowledge. They do not represent exact calculations. However, according to the current state of knowledge and under the assumptions made, the estimates provide a realistic indication of the actual savings in GHG emissions resulting from the operation of the PV, wind power and biogas installations supported by Rentenbank loans. This is confirmed by the plausibility checks performed, although the lack of more recent comparative values represents a certain limitation.

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Annex: Calculation Approach

The following sections describe the calculation approach in general as well as the data used and the assumptions made. A more detailed description of the approach can be found in Bickel (2020) for photovoltaic (PV) and wind energy plants. For biogas plants the approach is described in more detail in Bickel (2023).

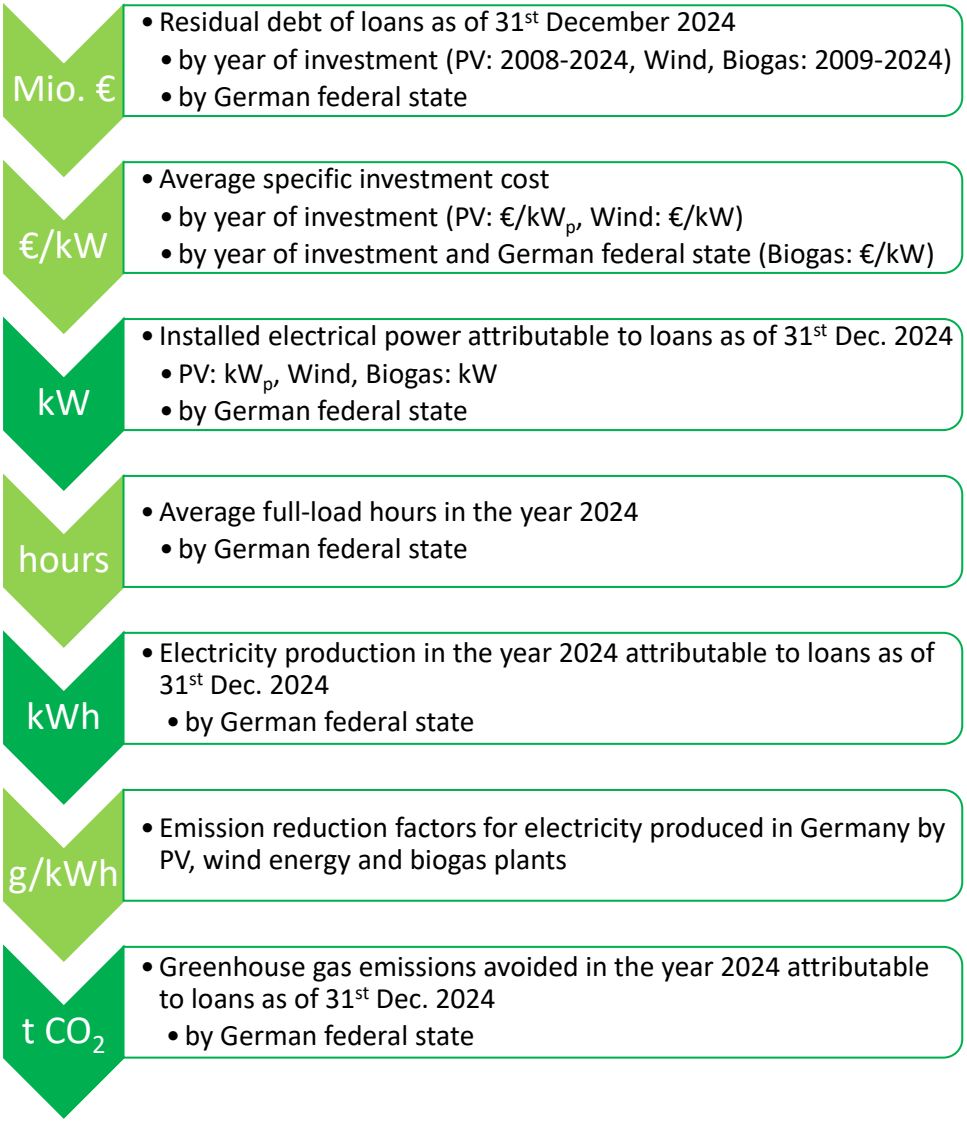

Figure 5: Overview of the calculation approach (light green arrows indicate input values, dark green arrows show calculation results).

The only information available on the PV, wind energy and biogas plants built with the support of Rentenbank loan programmes is the residual debt of loans as of 31st December 2024, categorised by year of investment and German federal state. This can be interpreted as share of the installations and their operation that is attributable to the loan programmes and is the starting point of the calculation. Figure 5 illustrates the calculation approach with light green arrows indicating input values and dark green arrows displaying calculation results.

One central assumption underlying the calculations is that the investment in wind energy, photovoltaic and biogas plants, is fully covered by the Rentenbank loans and that the investment is exempt of value-added tax. If the investment volume were higher than the loan, the GHG emission savings of the installations co-financed might be underestimated.

In lack of specific information on the plants supported, it was assumed that the year of investment corresponds to the year in which the facilities were put into operation. In case of a time gap of more than one year between investment and start of electricity production, the amount of GHG emissions avoided would be overestimated.

In the first calculation step, the installed electrical capacity can be estimated from the residual debt of loans using specific investment cost values. As the cost per kW of electrical power installed has changed over the last years, average values differentiated by year of investment are used for PV and wind installations. As for the previous years, average specific investment costs for the plants installed in Germany in the year 2024 were provided by ZSW.

For biogas plants, investment costs vary less over time than with different plant concepts (feedstock used, type of fermentation process) and the plant capacity. Average specific investments costs by federal state were derived by the average size of new plants commissioned in Germany based on data from the core energy market data register ("Marktstammdatenregister", www.marktstammdatenregister.de/MaStR) of the Bundesnetzagentur (German Federal Network Agency).

In the next step, the electricity production is calculated from the installed electrical power and average full-load hours in the year 2024. Full-load hours and thus the electricity produced by a PV or wind energy plant vary with geographical location within Germany. This is taken into account by using full-load hours differentiated by German federal state, which were derived based on data from DWD (2025) for wind energy and Anemos (2025) for photovoltaics. For biogas average full-load hours by federal state were derived based on Netztransparenz (2024). In lack of more recent data, values for the year 2023 had to be used for the operation of biogas plants in 2024.

The initial commissioning dates of new plants are distributed over the months of the calendar year, i.e. they produce electricity only for a part of the first year of operation. This is reflected in the common assumption that only half of the full-load hours are taken into consideration for the first year of operation. In other words: the plants that were built in 2024 were assumed to generate half of the electricity which they would have produced with a start of operation on January 1st 2024.

The final step is the multiplication of the electricity production by emission reduction factors for electricity produced in German PV, wind energy and biogas plants. These factors describe net emission savings, setting off the volume of emissions caused by the use of renewables (final energy supply) against the volume of gross emissions that are no longer being released due to fossil sources having been replaced with renewables. All upstream process chains

involved in the production and supply of the various energy sources and in installation construction and operation (but not dismantling) are considered. The factors are provided for emissions of CO_2 and CO_2-equivalents for PV, wind energy and biogas plants (as well as other renewable energy sources), by the German federal environmental agency ("Umweltbundesamt" - UBA). Table 6 shows the values for 2023, which is the most recent year available.

Table 6: Emission reduction factors for the year 2023.

g/kWh	CO_2	CO_{2eq}
Photovoltaic energy	642	690
Wind energy onshore	708	758
Biogas cogeneration	693	533[a)]

Source: UBA (2025), values rounded.

[a)] In line with RED II the GHG emission factor considers a bonus for plants using liquid manure as fermentation substrate. This leads to a higher emission reduction per kWh compared to previous years.

With respect to the uncertainties involved in the assessment it should be noted that the missing technical information on the installations supported by the loans imply considerable uncertainties. This is even more true for biogas plants than for PV and wind energy, because the specific investment costs strongly depend on plant concept and plant capacity. Therefore, the main and most important factor for improving the reliability of the estimates would be the provision of technical information on the facilities supported. In particular, data on the electrical capacity installed would be essential to eliminate the uncertainty involved in the estimation of the electrical capacity based on general specific investment costs.